Deciding The Level of Automation During the Design of Assembly Systems: Literature Review of Decision Methods and a New Approach Proposal

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DECIDING THE LEVEL OF AUTOMATION DURING THE DESIGN OF ASSEMBLY SYSTEMS: LITERATURE REVIEW OF DECISION METHODS AND A NEW APPROACH PROPOSAL

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ABSTRACT

This paper reviews research in the field of automation deciding for assembly systems design. The purpose is to analyze the already developed decision making methodologies in the topic, evaluating previous efforts against practical use by manufacturers in such complex and important decision. Based on this study, a procedure is proposed to support the decision making process regarding the automation throughout the workstations of assembly systems during early conceptual design phase. Requirements for the decision methods are defined. The evaluations and analyzes of existing methods lead to a new decision approach then evaluated against the identified requirements. It is tailored to assist systems designers and decision makers in the determination of the appropriate automation level for their assembly systems.

Keywords: Assembly System design, Level of Automation, Decision support

1 INTRODUCTION

Today's market is characterized by a difficult environment with international competition and globalized production. This is basically engendered by the pressure of competitive low cost emergent countries allowing manufacturers to reduce production costs by delocalizing. The challenge for countries with high labor costs is to remain competitive and save their local production. One of the tools used to tackle this issue is to increase automation levels. However, in the past few years, manufacturers realized that an increased usage of automation does not necessarily result in increased benefits [1]. Based on our team's experience in the field of Level of Automation (LoA) deciding and on multiple visits to different assembly manufacturers in France, Germany, and the United-States, it was seen that in spite of the high labor rate in these countries, manual assembly is still significantly used. In that sense Boothroyd [2] stated that "although during the last few decades, efforts have been made to reduce assembly costs by the application of high speed automation and, more recently, by the use of assembly robots, success has been quite limited. Many workers assembling mechanical products are still using the same basic tools as those employed at the time of the Industrial revolution". The challenge is then: How to select appropriate levels of automation throughout an assembly system to design in order to respond in a best way to a given manufacturer requirements considering the product features and the planned production?

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2 BACKGROUND AND MAJOR RESEARCH ORIENTATIONS IN AUTOMATION

The focus of researchers in assembly automation is generally technical and concentrated on improving performance, productivity, and autonomy of manufacturing processes. The first appearance and evolution of technological mechanical manufacturing paradigms from Flexible Manufacturing Systems over Reconfigurable Systems towards Autonomous Manufacturing Systems are shown and described in Table 1.

Table 1: Research tendencies in automation

Periods	1980s	1990s	Since 2000s
Market	Variety of products and small volume per product [3]	Customized products and fluctuating demand [3]	Personalized products and turbulent markets [3] and possibility to produce everywhere, particularly in emergent low cost competitive countries
Requirements in manufacturing	Flexibility [3]	Adaptability, changeability [3]	Self-Adaptability with a maximum of autonomy [3]
Tendency	Flexible systems [3]	Reconfigurable systems [3]	Autonomous systems [3], Lean automation and Industry 4.0 [4]

As it can be seen based on Table 1, the literature in automation seeks to improve processes technology, adaptability, and productivity [5] rather than the most appropriate system and automation levels considering a given planned production. This literature fails to explain how to select appropriate technological investments that best support a business [5]. A few of works are focused on human consideration in assembly lines and manual allocation of tasks in contrast of the voluminous technical literature in technical automation [6]. Even recently in 2010, it was also stated that the literature about LoA decision is not abundant and the support for making automation decisions is “poor” [7]. One of the core problems in the manufacturing context as well as in the automation literature, consists in the fact that the discussions on the question to automate or not, are not well documented and the path that leads to the final decision is not traceable [8]. In fact, the usefulness of automation is highly dependent on finding appropriate distribution of tasks between the human and the technical system [9]. This appropriate distribution consists in the main purpose of our study aiming at determining the right automation level for a given case with a better dimensioning of resources that has to match the product to assemble features, the required production information, the manufacturer’s context, constraints, preferences and best practices.

3 LEVEL OF AUTOMATION DECIDING LITERATURE METHODS

The Level of Automation (LoA) can be defined as the degree of automation [10], the process technology [11], or the tasks allocations between humans and machines [12]. . In this section, a literature review is made presenting methods that can be used for LoA deciding. These methods are analyzed with regard to requirements, drawn for a better suitability to the purpose of LoA deciding during the design of assembly systems.

3.1 Literature review in automation decision methods

Eleven methods in automation deciding were found in the literature. In Table 2, the methods are presented and classified according to the kind of the method structure. We identified 4 types of method: decision flow-charts, decision guidelines, decision tables, and parametric cost computation-based.

Table 2: Existing LoA methods in the literature

Class	LoA Methods		Description
Flow-charts	***M1***	[8]	Product **complexity** and impact on effort to automate and cost.
	M2	[13]	Answering to some questions related to planned production leading to a **'manual', 'hybrid', or 'automated'** process as automation solutions.
Guidelines	***M3***	[14]	The USA **Principle**: « Understand, Simplify, Automate » for an existing system to improve.
	M4	[6]	**Human performance** consideration in automation.
	M5	[7]	Dynamo **guideline in 8 steps**: manufacturer involving in the decision by measuring actual LoA and suggesting possible improvements.
	M6	[15]	Dynamo++ **guideline in 12 steps**: Dynamo method adjusted.
	M7	[16]	**Quality** oriented approach using QFD (Quality Function Deployment) and FMEA (Failure Mode and Effects Analysis) methods.
Decision Table	***M8***	[17]	Automation deciding **table** for a given workstation involving some **criteria** concerning the **product** to assemble and **the planned production** information.
Cost-based	***M9***	[12]	A **cost model for manufacturing** cost computing with minimization issue. LoA is then defined as the quotient of personnel cost to the sum of personnel and machines costs.
	M10	[18]	**Cost** estimating for different solutions and profitability consideration with **assembly time estimating** for cost time-based computing.
	M11	[10]	LoA measurement and improvement analysis considering mostly a simple way to compute the **cost**. Secondary briefly considered aspects are **productivity**, **quality**, and **flexibility**.

3.2 Our requirements definition and literature methods requirements matching

The aim of this section is to evaluate the LoA literature methods from applicability and efficiency points of view for the sake of automation decision making in assembly. We list the requirements (Ri) in a first sub-section before evaluating and analysing the LoA methods.

3.2.1 Requirements for LoA deciding

As our goal is to find a method for automation deciding in assembly systems design, an appropriate method should be **applicable** during the **early phase of new assembly systems design** where the system is not existent and is to be designed **(R1)**. In fact, some methods are dedicated to manufacturing and not applicable in assembly. The LoA choice has strong implication in the system design. Therefore, the good alternative must be selected the sooner possible. Working at this phase, still offer the possibility to propose changes in the product design. A good decision method should also be **objective (R2)** because we need a decision mostly driven by the method itself than by expert intuition for standardization and applicability issues. The method should be **analytic (R3)**: a low level of granularity analysis with tasks and resources detailed are required for an assembly system design. It should **allow partial automation (R4)** because the finality is to inform where to automate or not throughout the process rather than a general decision of automating or not the whole process. The goal is to optimize the assembly systems considering the heterogeneous tasks and techniques that can be used to assemble a given product. The method should consider **cost** computing and minimizing because the cost is one of the most preponderant decision criteria for every manufacturer **(R5)**. The method should involve the **manufacturer context and capabilities** within the decision **criteria (R6)** for a better suitability to a given manufacturer, product design, and planned production. Finally, the path leading to the final decision should be **traceable** and **justifiable (R7)** so that the optimal solution to propose can be reused, argued, discussed, analyzed, and probably manually improved again by the manufacturer if limits of the solution are identified.

3.2.2 Evaluating LoA methods

In Table 3, the LoA methods are evaluated with regard to the defined requirements.

Table 3: Literature LoA methods evaluation

LoA Methods		LoA methods evaluating and requirements matching						
		R1	R2	R3	R4	R5	R6	R7
M1	[8]	✓	✓	✓	✓	✓		
M2	[13]	✓	✓				✓	
M3	[14]			✓	✓			
M4	[6]	✓			✓	✓	✓	
M5	[7]			✓	✓		✓	✓
M6	[15]			✓	✓		✓	✓
M7	[16]	✓			✓		✓	✓
M8	[17]	✓	✓			✓	✓	
M9	[12]		✓		✓	✓		✓
M10	[18]	✓	✓	✓		✓		✓
M11	[10]		✓	✓	✓	✓	✓	

Based on Table 3, it can be seen that no method is fulfilling all requirements. Most promising ones are the decision flowchart defined by Ross (M1) and two cost based methods: the one defined by Boothroyd et Al (M10) and the approach defined by Gorlach and Wessel (M11). Method M1 is fulfilling 5 requirements. Yet, it is only an outline (class C1 in Table 2) and the way to apply it is not presented. In fact, it is based on cost minimizing to assess the effort to automate operations. Nevertheless, the cost model to be used is not detailed. It is also involving too few criteria (R6). Method M10 is interesting because of its analytic way of analyzing assembly operations with time estimates. But, it neglects providing suggestions for partial automation (R4) and it is not involving criteria considering the manufacturer itself and his capabilities (e.g. potential for investing, expertise, or technical preferences). For method M11, we guess it is of interest even if it is dedicated to existing processes (not applicable during the early phase). It is valuable in deploying the idea of computing the cost for different alternatives with a simple model. It supports an objective evaluation and adopts an analytical way to allow several parameters involving in the cost related to product and production, with some manufacturer criteria such as the location, labor skills, experience, and resulting quality. Yet, only four decision criteria are considered: cost, productivity, quality, and flexibility. Then, only the cost criterion is well tackled. In fact, the quantification, evaluation, and integration of the three remaining ones are not explained.

For the different encountered LoA methods (M1 to M11), a lack of visibility about the physical process representation is noted. In fact, representing the assembly sequence and its link to the product design is crucial to design the assembly system [19]. Moreover, no method takes into account the possibility of generating different alternatives and evaluating them. In addition, the assembly sequence may be developed essentially independently of the technology choices [19]. Few LoA criteria are considered in the existing methods while we identified in an industrial benchmark about 70 criteria influencing the LoA decision.

The reviewed methods are globally lacking of traceability of the decision process. No computerization can be possible for most of the methods, with no possibility to compare or evaluate different alternatives of assembly systems. A need to define a method providing an objective way to decide and compare alternatives is arising. This method should fulfill the requirements of section 3.2.1. To our understanding, a good method should also use process modelling with a possibility to generate and evaluate alternatives with regard to LoA criteria that have to be considered during the decision. The focus is to base the reasoning on the analysis of the product design, the feasible assembly sequences, the planned production information, and the manufacturer's context.

4 A NEW METHOD PROPOSAL FOR AUTOMATION DECIDING

In this section, our methodology for LoA deciding is proposed. This methodology consists in a framework with different capabilities for modelling alternatives and for guiding the decision. In a first subsection, the whole decision process involving the different decision criteria is defined. In the remaining sub-sections, the related developments allowing the implementation are presented.

4.1 The decision approach

We define first the decision approach for LoA optimizing and deciding (Figure 1) based on the product design, production information, and the strategic manufacturer requirements and criteria.

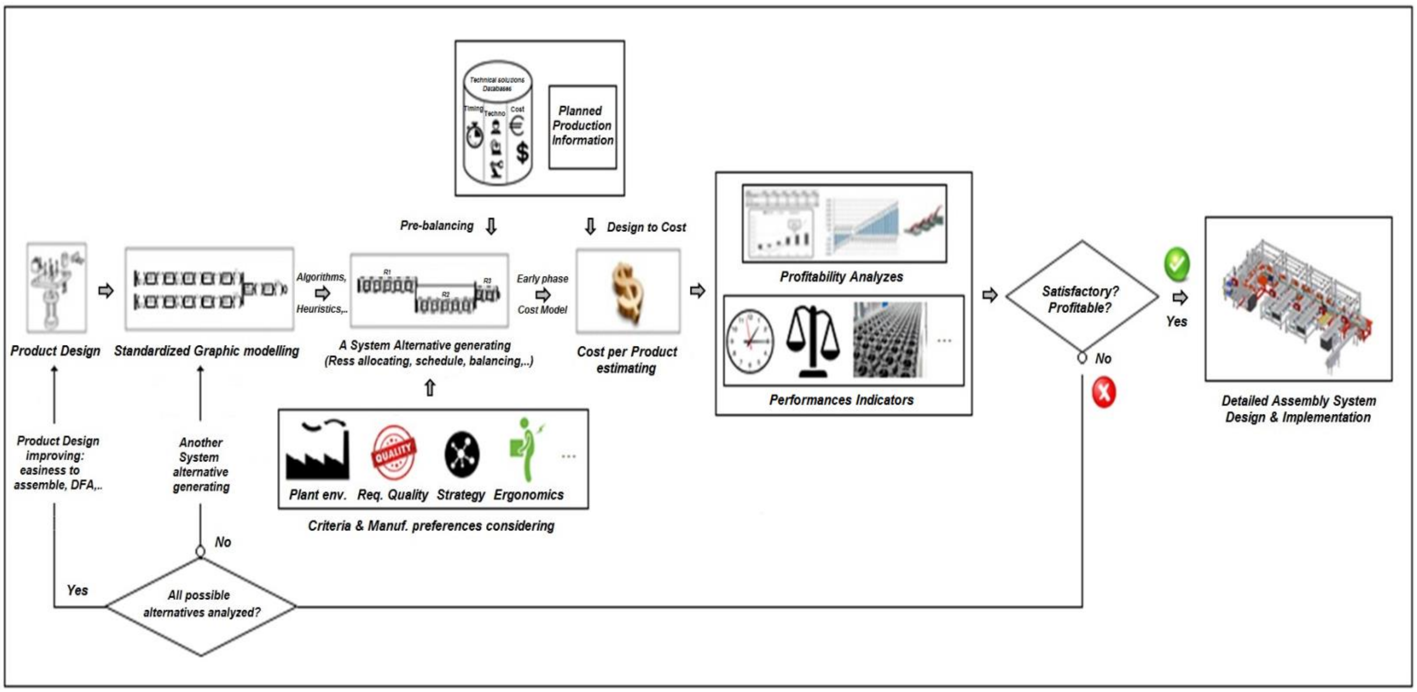

***Figure 1**: The Proposed LoA Approach (a simplified scheme)*

As it can be seen in Figure 1, the approach starts with a graphic model representing the assembly motions based on the product design analysis and assembly sequence. Then assembly system alternatives are generated with appropriate resources dimensioning have to be established considering balancing and Lean principles using planned production information (volume, production life, Takt time, etc). Criteria considering will allow authorizing, imposing, or forbidding certain choices of automation according to feasibility issues (e.g. ergonomics), manufacturer choices, or best practices. A cost per product is then to be computed using an appropriate cost model considering the graph's motions time estimates, the mentioned planned production information, and standard costs databases for the different technologies (initial machine cost, electricity consumption, cost of maintenance, etc..). This process is performed in an iterative way considering designers feedbacks. New alternatives may be generated and evaluated with regard to criteria, cost, and performances. The best alternative is kept at the end. In the case of non-feasibility, non-profitability, or any kind of non-satisfactory solutions, a loop will lead to the product redesign in order to improve the easiness of assembly using DFA (Design For Assembly) rules. A graphic representation should support the alternatives generation. It is detailed in the next subsection.

4.2 The process modelling supporting the design and automation reasoning

The sequence representation is utilized as a basis to initiate the analysis of the right LoA to implement. After defining what we require from an assembly representation, a literature review in the field of assembly modeling languages and tools was performed [20]. The study led to a new modeling language labeled "Assembly Sequences Modeling Language (ASML)" [20] dedicated to automation and design issues.

This language allows a standardized description of the assembly sequence with required resources representation. ASML as a graphic language, uses standardized basic graphic elements allowing graphically representing assembly sequences and deducing processes [20]. It is associated to a standardized assembly vocabulary from [20]. This vocabulary is dedicated to assembly motions and work instructions description allowing describing assembly processes. The approach begins by building a first standardized ASML scheme which follows the product design block. If several assembly sequences are possible, multiple initial ASML models can be edited and analyzed.

Based on the first standardized ASML model, the language allows resources allocating and representing by grouping assembly motions in tasks and setting their executing resources with associated technologies [20]. It provides ways to manage resources availabilities, conflicts and collisions [20]. Using these principles, multiple assembly systems alternatives can be defined starting from a product dependant generic scheme. Alternatives are distinguished by the resources allocations to tasks and the LoA fixed for the various resources [20]. In our research, we use a four LoA scale to describe resources technologies respectively from the lowest (LoA = 1) to the highest (LoA = 4): manual, manual with automated tool, automatic, and robotic.

Each standardized assembly motion utilized in the model may be time estimated [20]. Consequently, based on the motions figuring in the ASML representation, and considering the standardized structure of the model (serial, parallel, choices, etc) [20], the assembly time for a given assembly alternative (Lead Time, Takt Time) can be estimated using defined rules associated to a database of time standards that we built [21].

4.3 Involving more LoA criteria in the decision procedure

As previously mentioned, about 70 criteria involved in LoA deciding were identified through literature analysis, workshops and benchmarking. Some of the most preponderant criteria concerns: the assembly cost per product, quality, productivity and required production, time performances, product design features (parts thickness, dimensions, weight, slipping, etc,..) and its complexity impact on automating for several reasons: time,cost, flexibility, ergonomics, manufacturer context, environment, culture, workers skills and expertise, the aptitude to accept the changes, and so on.

An LoA method should support the consideration of the criteria to involve for a given manufacturer. In our proposed method, some preponderant criteria are considered using flags for imposing or forbidding some technology choices for various tasks throughout the assembly process. The criteria will be considered using the manufacturer recommendations and best practices for the local assembly, the product parts features to assemble, etc. Other criteria are considered by forming performance indicators: cycle time, initial investment, volume aptitude, process amortization period, and so on, combined with thresholds definition. The way to consider additional criteria as the flexibility related ones is still under development.

4.4 A supporting software environment

A computerized tool developing for LoA decision making got already started. A JAVA application was previously developed allowing entering a process ASML modelled in the software and time estimating. A new version is currently under development. The idea is to build an integrated software tool with a Graphic User Interface (GUI) in which the user enters the initial generic ASML model of the process. Algorithms of alternatives generations and evaluations with regard to the different LoA criteria with performances indicators computing are actually under development.

5 DISCUSSION AND FUTURE WORKS

The proposed method for LoA seems to be promising. It was conceived so that it fulfils all the identified LoA requirements defined in section 3.2.1. The method has also additional contributions such as assembly processes modelling and different systems alternatives generating and assessing [20]. The adopted method for modelling allows considering important aspects such as assembly systems time estimating, resources appropriate dimensioning, and early lines balancing [21]. A cost model nearly finalized will allow computing the assembly cost and perform the optimization loop defined in figure 1. Several identified LoA criteria will also be integrated to the method that seems sufficiently opened to add various kinds of criteria. Algorithms for alternatives generation are also under development. They mix the exploration of the solution space with the identification of the manufacturer's restrictive criteria, in order to guide most suitable alternatives generating. Another axe for resolving the problem can be linear programming that would need a complete mathematical modelling of the whole problem which implies heterogeneous and complex criteria with scheduling aspects. We are also proceeding in parallel to industrial validations with a computerization of the whole methodology and development of case studies.

6 CONCLUSION

A review in automation deciding for assembly systems was presented in this paper. The different methods in LoA deciding were presented and evaluated with regard to defined requirements. The lack of a satisfactory method fulfilling our requirements led to a new method proposal. This method is discussed. Its main originalities are to focus on alternatives generation and to draw an enough flexible framework to include various kinds of decision criteria. The whole proposition is under experiments and validations on industrial case studies with process modelling and alternatives suggestions with optimal automation levels reasoning. Proposals can be then discussed with manufacturers and compared to what they could design. Validations can show the limits of the approach and suggest improvements to the solutions to obtain and to the whole decision process.

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